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# HYDRAULIC ANALYSIS AND IMPROVEMENT OF WATER DISTRIBUTION NETWORKS OF DUTSE METROPOLIS, NIGERIA

**T. O. Rasheed and S. Dan'azumi***
*(Department of Civil Engineering, Faculty of Engineering, Bayero University Kano, Nigeria)*
***Corresponding Author's Email address:** sdanazumi.civ@buk.edu.ng

**Abstract**
In order to satisfy the water demand of the continuously growing population, it is essential to provide an adequate quantity of water through a well-designed network of pipes in Dutse Metropolis of Jigawa State, Nigeria. Insufficient network coverage in commensurate with the rapid infrastructural development and inadequate supply of water to Dutse Metropolis has, over the years, caused hardship to people in the town. Presently, the system produces a total of 1,801,728l/d against the current demand of 7,793,760 l/d indicating a gross deficiency of up to 76.9%. This study employed EPANET 2.0 to conduct hydraulic analysis of water distribution in Dutse Metropolis with a view to propose improvement measures. Results indicated that water coverage in the present network can only reach 70.45% of the town for only 2 hours at the desired pressure head. The water demand of the town was projected to 2026 and found to be 9,975,960 l/d. The network was re-designed to meet the future demands and results indicated that the new network can supply water for an extended period of 15 hours with 95% of the area having pressure head varying from 25-65 m and flow above the minimum recommended value of 0.3 l/s. The proposed pipe reticulation is estimated to cost N1,207,892,686. The outcome of the study was recommended to the Government for strategic planning and implementation application.

**Keyword:** Hydraulic analysis, Water supply, Dutse, Jigawa, EPANET

## 1. Introduction
From the beginning of human civilization, people have settled close to water sources along rivers, lakes or natural springs. Those that live in water scarce areas have to carry water over long distances causing a lot of difficulties. Due to these problems, they tended to use nearby sources of doubtful quality that may be contaminated, thus posing danger to public health (Aliko, 2007).Water distribution networks are part of the master planning of municipalities. Their planning and design require the expertise of city planners and engineers, who must consider many factors such as: location, demand, future growth, pressure, pipe size and fire fighting flows.(Anisha *et al.,* 2016). Therefore, it is necessary to plan and construct suitable water distribution network in order to ensure the availability of water to the various sections of the community in accordance with their demand and other requirements (Anil, 2004).

The objective of any water supply system is to provide water of sufficient quantity at the desired pressure to the consumers' tap. The water may be pumped directly into the distribution pipes or stored in elevated reservoir and then fed into the distribution pipes. The hydraulic analysis of pipe network is a relatively complex problem particularly if the network consists of range of pipes as frequently occurs in water distribution systems of large metropolitan areas.The analysis involves specifying the optimal sizes of different elements of the distribution network and checking the adequacy of the network for flow and pressure head (Abubakar and Sagar, 2013). The performance of the system can be judged on the basis of pressure available in the system for a specific rate of flow. Thus, pumps, storage and service reservoir are essential components of water distribution system. The engineer faced with the design or modifications to an existing system, has to select the sizes of pipes and other components (pumps and valves) in order to supply the required water at adequate pressure (Punmia, 1995).

Many methods have been used in the past to compute flows in network of pipes. Such methods range from graphical methods to the use of physical analogies and the use of mathematical models (Ormsbee, 2006). Analysis of a pipe network can be carried out using steady state

simulation or extended period simulation (EPS). The analysis is carried out using iterative solutions of flow in pipe networks such as Hardy Cross, Newton Raphson, linear theory and gradient algorithm. These methods are best implemented using computer software, and various software are available for commercial and educational use such as EPANET 2.0, WADISO SA, WaterCAD, WADSOP, MIKE NET and Pipe2000, (Roger,2002). The software basically computes the pipe flow and nodal pressure head given the nodal demands and other topographical features (Venkata *et al.,* 2015).

Adeleke and Olawale (2013) developed a computer program of pipe network analysis using the Hardy Cross method. The program was written using Java programming language and the computer simulated results compared well with manual calculations. Arunkumar and Mariappan (2011) evaluated and assessed public water supply system with the help of EPANET 2.0 software for the systematic planning and operation of water distribution system in Chennai, India. From the results, it was noted that an intermittent supply of 6 hours per day over a design period of 30 years is achievable with a pressure head of not less than 12 m. Ramesh *et al.* (2012) used geographical information system based census data to estimate water demand and design transmission and distribution lines to meet the requirement of future water demand inAlnavar, Karnataka, India. The pipe network system was simulated for different inputs of demands using EPANET 2.0. Results obtained from the EPANET software were cross-checked against calculations with hydraulic equations and found to be accurate. Mohapatra *et al.* (2012) studied the efficiency of water supply system in Nagpur, India. EPANET and ArcGIS were used to assess a continuous as well as intermittent water supply system and the simulation results indicated a pressure range between 4-10 m in the continuous system and pressure range between 0-8 m in the intermittent system which fall below the recommended value of 12 m. Dan'azumi and Abdullahi (2017) assessed the hydraulic performance of Bauchi Metropolis' water distribution network and found that the water allocation in the year 2015 can only be sustained for a period of four hours per day at a reasonable pressure head. An improvement was proposed for the future (2035) and then simulated in EPANET. Results indicated that, when implemented, the network could deliver sufficient water to more than 87% of the town at the minimum pressure head of 25 m.

The irregular terrain, increasing population, inadequate pipe network coverage and shortfall of water supply in Dutse Metropolis has, over the years, limited water distribution coverage.These conditions have put the populace to undue stresses and risk of water borne diseases. The combined daily water production from the metropolitan pumping stations were determined to be 1,801.73 $m^3$ against a total demand of 7,793.76 $m^3$ per day currently (JSWB, 2016). This is a gross deficiency which amount to 76.9%. It was therefore, seen that the existing water distribution networks can be analysed easily using computer software and problems associated with water supply of the city can be assessed so that measures to improve the situation can be adopted. This conclusion was further corroborated by Alkali *et al.* (2017) for Maiduguri township. Therefore, this research is aimed to conduct hydraulic analysis of Dutse Metropolis' water distribution networks using EPANET software with a view to propose improvement measures.

## 2. Material and Methods

### 2.1 The Study Area

Jigawa is one of thirty-six states of Nigeria. It is situated in the North-Western part of the country bordered by Kano and Katsina States to the West, Bauchi State to the East and Yobe State to the Northeast as shown in Figure 1. Dutse, the capital of Jigawa State, is the most densely populated area of the State (NPC, 2006) having total population of 153,192 with a growth rate of 2.8% per annum. It lies between latitude $11^0$ 46'39''N and longitude $9^0$ 20'3''E and occupies an area of about 113 square kilometers (Canback, 2008**)**.

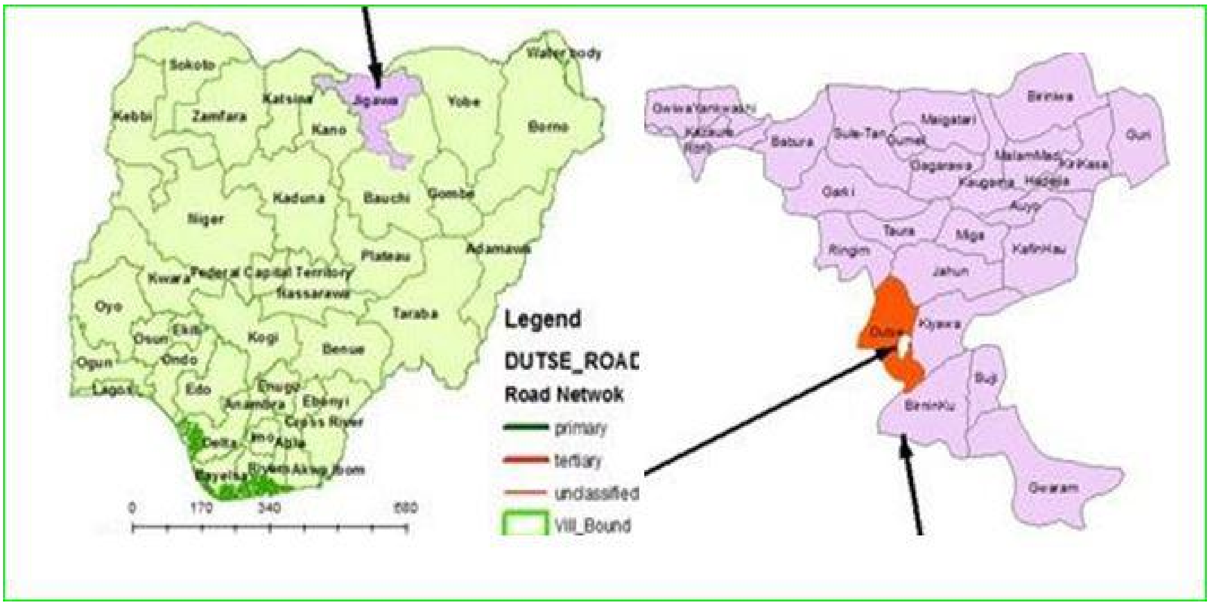


**Figure 1:** Map of Nigeria showing Jigawa State and Dutse LGA.(Source: www.maps-streetview.com/Nigeria/Dutse/, 2017)

## 2.2 Population Projection and Water Demand Estimation

According to the population census figure of 2006, Dutse Metropolis had a population of 50,741 and a growth rate of 2.8% (NPC, 2006). The population was projected to 2026 using geometric increase method according to Eqn (1) because it is suitable to cities that are yet to fully develop and are expected to grow rapidly (Singh, 2003).

$$P_n = P_o\left(1 + \frac{I_g}{100}\right)^n \qquad (1)$$

where: $P_n$ stands for the future population after $n$ decades, $Po$ represents the present population, $I_g$ is average percentage increase per decades and $n$ represents number of decades

Using the 2006 population census and a per capita daily consumption of 120 litres, the projected population is shown in Table 1. Distribution systems should be designed to adequately handle the peak hourly demand or maximum daily demand. Therefore, peak hour demand factor of 2 was adopted (Al layla, et al., 1977; Fair and Geyer, 1958). Various components of water demand were estimated as percntages of the domestic demand (Singh, 2003) and the nodal drawn off was calculated by dividing the total nodal drawn off with the number of nodes in the system.

**Table 1:** Population projection results

| Year | 2006 | 2016 | 2026 |
|---|---|---|---|
| **Population** | 50,741 | 64,948 | 83,133 |

## 2.3 Mapping and Hydraulic Simulation

A detailed map of Dutse municipal was obtained for pipeline alignment. The maps were obtained from Dutse Capital Development Authority and Google Earth. The maps were correlated to produce a base map, on which the proposed system layout was drawn. The whole project area was inspected to verify, validate and update the information on the source maps. In order to work spatially with the base map in ArcGIS, it is necessary to align it with existing geographically referenced data and this process is called geo-referencing. Using the ArcGIS software, the Dutse base map was geo-referenced. Nodal elevations were determined using geographical position system (GPS) and digital elevation model (DEM) from ArcGIS software. The data obtained was correlated and assigned to the network nodal points (Figure 2) and the skeletized pipe network

layout was exported to EPANET for hydraulic simulations and analysis (Rossman, 2000). Hydraulic elements data namely: pipe diameter, roghness, tank capacity and elevations and reservoir capacity and elevations, nodal elevations, base demands values and Darcy-Weisbach formulae (Eqn 2) were entered in to the EPANET and the software was run using an extended period simulation (EPS) of 2 hours, in order to investigate the response of the existing network due to a continuous supply of only 2 hours per day from the very limited sources. EPANET then computes the rate of flow, velocity and headloss in each pipe and the pressure head at each node.

$$h_f = \frac{flv^2}{2gd} \quad (2)$$

where $h_f$ stands for friction headloss, $f$ is the friction factor, $v$ is the pipe flow velocity, $l$ and $d$ are length and diameter of the pipe respectively.

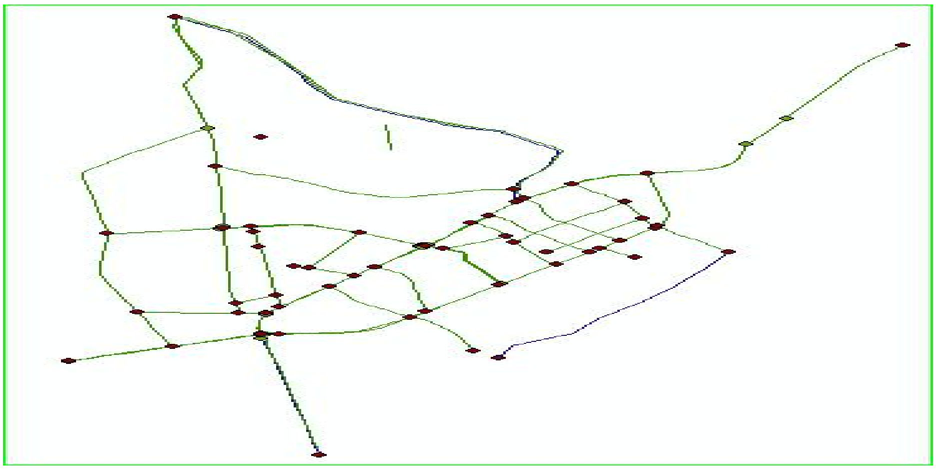

**Figure 2:** Existing pipe network from ArcGIS

The network was re-designed, to cover more areas and its capacity was increased by adding more reservoirs. In order to have adequate storage, the distribution reservoirs need to be of larger capacities: i.e.: Shuwarin Reservoirs was upgraded to 4,000 $m^3$, Gidan Ihu Reservoirs was increased to 2,000 $m^3$, Hill Top Reservoir was raised to 5,340 $m^3$, Burtilan Reservoir was upgraded to 5,340 $m^3$ and remaining six distribution reservoirs at Kachi, Mobile Base, Old Model, Takur Adua, Takur Site and Inuwa Estate were increased to 2,136 $m^3$ each. The improved design was then re-analysed using an EPS of 15 hours a day.

The final design for the reticulation was estmated using Bill of Engineering Measurement and Evaluation (BEME) using UPVC pipes with pressure ratings of 10 bar. The cost was obtained from PANAR Ltd (Pipe manufacturers) and Cosi-Chimax Ventures Ltd (Dealers) Kano.

## 3. Results and Discussion

### 3.1 Water Demand Componnts and Nodal Drawn Off

The various water demand components estimated as well as the nodal drawn off are presented in Table 2. The unit nodal dran off represents the average water drawn off from each node under the current and future scenarios.

**Table 2:** Nodal drawn off estimation

| Year | Demand (l/d) | Demand (l/s) | Fire demand 10% (l/s) | Comm. and Ind. Demand 10% (l/s) | Unaccounted for water 15% (l/s) | Public use 5% (l/s) | Minor loss 5% (l/s) | Total nodal drawn off (l/s) | Unit Nodal drawn off (l/s) |
|---|---|---|---|---|---|---|---|---|---|
| 2016 | 7,793,760 | 90.21 | 9.02 | 9.02 | 13.53 | 4.51 | 4.51 | 130.80 | 2.97 |
| 2026 | 9,975,960 | 115.46 | 11.55 | 11.55 | 17.32 | 5.77 | 5.77 | 167.42 | 2.26 |

### 3.2 Nodal Pressure Head and Links Flow at 2 Hours EPS

The current demand under existing pipe network was analysed for 2 hours EPS. The system recorded minimum residual pressure of 2.44 m at Node 24 around Garu area and maximum pressure of 47.15m at Node 5 around Takur Adua Area. Negative pressure of -8.86m was recorded at Node16 near Sabo Takur Area. Out of 44 nodes, 33 recorded adequate pressure range of 25-47.15m, 10 nodes gave inadequate pressure value below the designed value range of 25-65 m. Bhardiwaj (2001) recommended a minimum residual pressure of 25-28m and a maximum of 70-84m, American Water Works Association (AWWA) stipulated a pressure range of 15-70m while Philippines Water Supply Manual (2012) recommended a minimum of 3m and a maximum of 70m. Therefore a pressure range of 25–65m was adopted in this research and 75% of the entire nodes have a pressure head as shown in Figure 3, which is okay when the network is operated for only 2 hours a day.

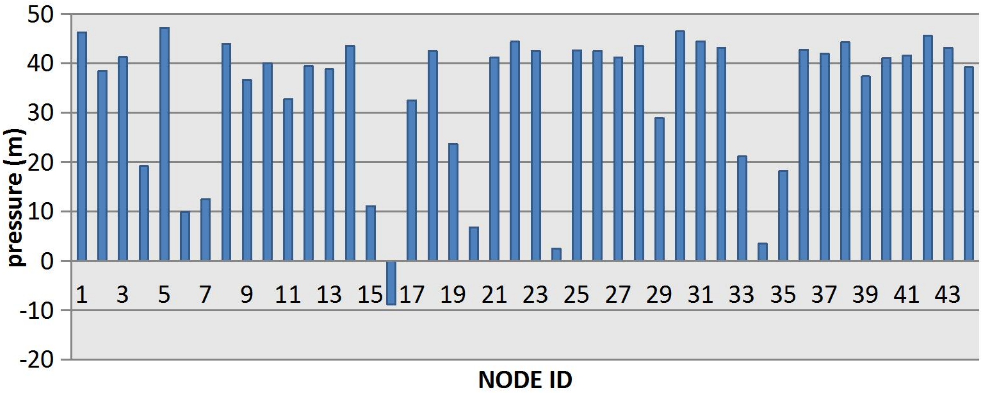


**Figure 3:** Nodal pressure head at 2 hours EPS

The links flow rate results at the 2 hours EPS revealed that the maximum flow of 48.64 l/s occurred along Link P2 and minimum flow of 0.40 l/s along Link P22. Out of 60 links 4 links recorded flow below 0.30 l/s. Building code compliance document sets out acceptable minimum flow rates in pipes at 0.30 l/s and the velocity must not exceed 3.0 m/s (Adeniran and Oyelowo, 2013). Therefore 93.3% of the links show a remarkable flow that is well sufficient for building service pipe connections and for fire hydrant service installations as shown in Figure 4. Eventhough, this scenario simulates the current condition of the network, two hours water supply in an urban area is not adequate and hence the need for improvement.

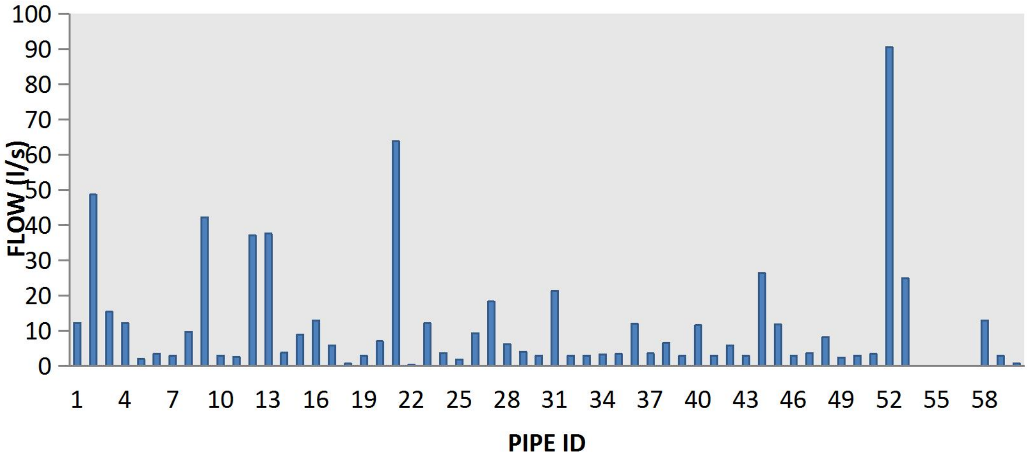


**Figure 4:** Links flow at 2 hours EPS

### 3.3 Nodal Pressure Head and Links Flow for Improved Design

Figure 5 shows the improved and extended network covering more areas.

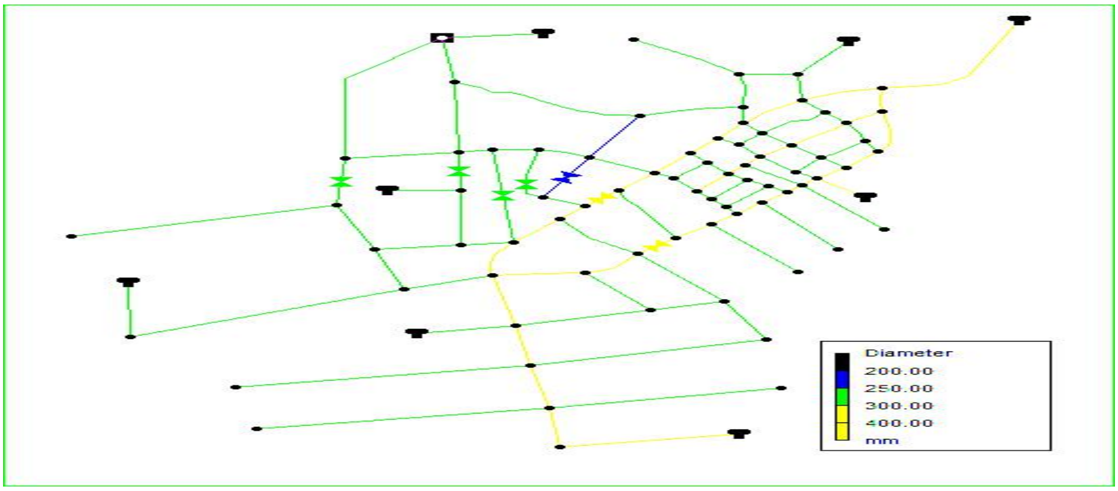


**Figure 5:** The improved Dutse network with proposed pipe sizes

The hydraulic simulation for the re-designed network was carried out for an EPS of 15 hours and results are presented in Figure 6. It could be seen that the minimum residual pressure of18.46m was recorded at Node J6 around NNPC Filing Station close to Hilltop Tank while maximum pressure of 70.34m was recorded at Node J38 near Jigawa Tsada Area. Out of 74 nodes, 70 recorded pressure values between 25-64m and only one node J73 around Marabusawa/Garu Area recorded a negative pressure head. This area is hilly, but the situation has been taken care up by Jigawa State Water Board in which a booster station is installed to boost water to the 482m elevation. Generally, 94.6% of the entire nodes have adequate residual pressure as shown in Figure 6

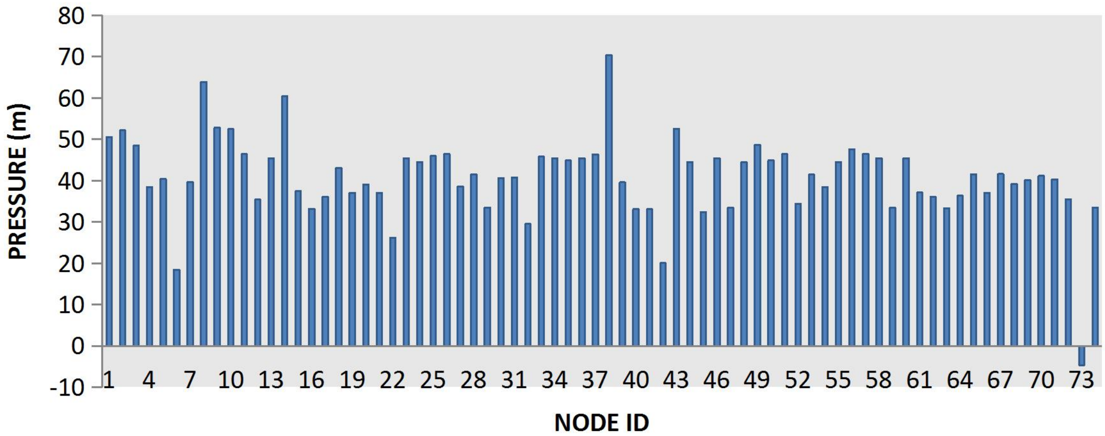


**Figure 6:** Nodal pressure head at 15 hours EPS

The links flow rate for this scenario shows that the maximum flow of 82.20 l/s was recorded at Link P6 while minimum flow of 0.11 l/s was recorded at Link P71. Out of 108 links, only 4 links recorded flow below the minimum recommended value of 0.3 l/s. With this, it can be said that 96.3% of the entire links have adequate flow as shown in Figure 7. These flow rates are adequate for building service pipe connections, fire hydrant installations and other utilities.

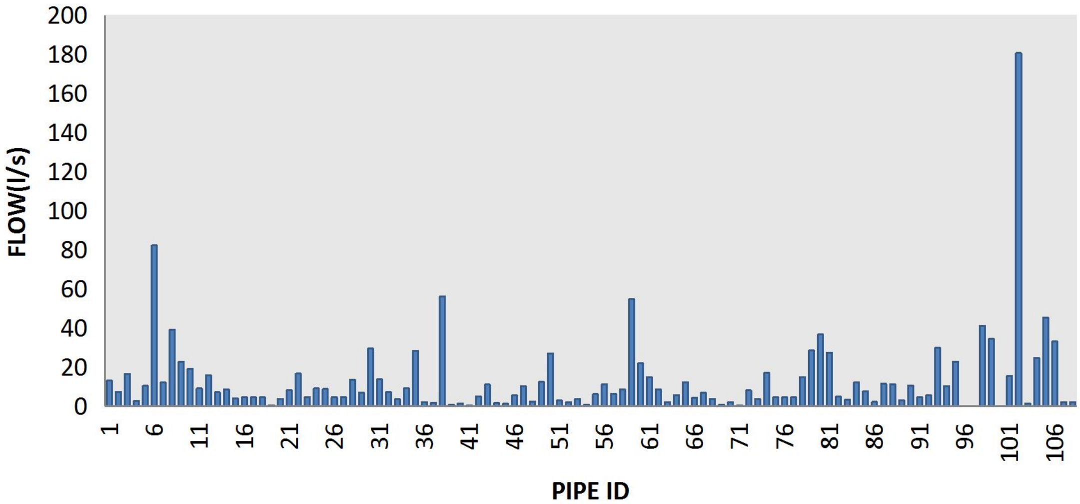


**Figure 7:** Links flow at 15 hours EPS

The improved pipe reticulation network is estimated to cost N1,207,892,686 if UPVC pipe is to be used. The improved design was carried out assuming the following appurtenances are in placeand therefore the research also recommended upgrading of Shuwarin reservoirs to 4,000 $m^3$, Gidan Ihu reservoirs to 2,000 $m^3$, Hill top reservoir to 5,340 $m^3$, Burtilan reservoir to 5,340 $m^3$ and remaining six distribution reservoirs at Kachi, Mobile base, Old Model, Takur Adua, Takur Site and Inuwa Estate to 2,136 $m^3$ each. However, the cost of new and improved reservoirs as well as that of additional boreholes has not been estimated in this work.

## 4. Conclusions

The present daily water production in Dutse Metropolis was appraised to be 1,801,728 litres against an existing demand of 7,793,760 litres indicating a deficiency of 76.9%. Therefore, hydraulic analysis of Dutse Metropolis' water distribution networks was carried out with a view to analyse the hydraulic performance of the existing network and propose improvement in the current and future water supply. The current population was determined and the population was projected to 2026, geometric growth model was used and the projected daily water demand of 9,975,960 litres was estimated. The current network was simulated with EPANET and it was found that the water supply can only be sustained at required pressure for only 2 hours duration. The entire network was re-designed to meet the current and future water demand. The re-designed network can adequately deliver water for a total duration of 15 hours against the existing 2 hours supply. It is recommended that more boreholes need to be sunk to boost water production and the network needs further extension. The improved pipe reticulation network is estimated to cost N1,207,892,686 if UPVC pipe is to be used. The research also recommended upgrading of Shuwarin reservoirs to 4,000 $m^3$, Gidan Ihu reservoirs to 2,000 $m^3$, Hill top reservoir to 5,340 $m^3$, Burtilan reservoir to 5,340 $m^3$ and remaining six distribution reservoirs at Kachi, Mobile base, Old Model, Takur Adua, Takur Site and Inuwa Estate to 2,136 $m^3$ each. It is expected that, if the recommendations given are implementated, Dutse metropolis will be served with water of sufficient quantity. This will also go along way in mitigating the spate of water borne deseases in the city.

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